

Hadronic physics at KLOE

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Abstract. New KLOE results on scalar mesons, $\gamma\gamma$ physics and η physics are presented.

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1. SCALAR PHYSICS

The structure of the scalars below 1 GeV needs to be further clarified. Several models have been proposed to describe them (e.g. $q\bar{q}$, four quarks, $K\bar{K}$ molecules, etc.). The decay of the scalars into two pseudoscalars ($S \rightarrow PP'$) can be used to investigate their nature because the branching ratios and the invariant mass of the two pseudoscalars are sensitive to the scalar structure.

$\phi \rightarrow a_0(980)\gamma \rightarrow \eta\pi^0\gamma$ decay [1]. For this measurement about 400 pb⁻¹ of KLOE collected data have been used. The analysis has been performed for two different η final states, i.e. $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$. A kinematic fit has been performed imposing the four momentum conservation, the photon velocity and the invariant masses of both η and π^0 . The $\eta\pi^0$ invariant mass distribution has been fitted with the “no-structure”[2] and the “kaon loop”[3] models after background subtraction. The results of the fit are shown in table 1. It is interesting to note that both models give a large coupling of the $a_0(980)$ with the ϕ meson, indicating a sizable strange quark content in the $a_0(980)$. The branching ratio obtained for the two different decay chains are in agreement: $BR(\phi \rightarrow \eta\pi^0\gamma) = (7.01 \pm 0.10_{stat.} \pm 0.20_{syst.}) \times 10^{-5}$ for the $\eta \rightarrow \gamma\gamma$ final state and $BR(\phi \rightarrow \eta\pi^0\gamma) = (7.12 \pm 0.13_{stat.} \pm 0.22_{syst.}) \times 10^{-5}$ for the $\eta \rightarrow \pi^+\pi^-\pi^0$ final state.

$\phi \rightarrow K^0\bar{K}^0\gamma$ decay [4]. This decay allegedly proceeds through the intermediate $f_0(980)$ (I=0) and $a_0(980)$ (I=1) scalar mesons: $\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0\bar{K}^0\gamma$. The kaon pair is produced in a $J^{PC} = 0^{++}$ state, so the two kaons are both K_S or K_L . We have searched for a final state with a $K_S K_S$, with both K_S ' decaying to $\pi^+\pi^-$. This request

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TABLE 1. Output of the fit to the $\eta\pi^0$ invariant mass with two different models: kaon loop and no structure.

	Kaon loop	No structure
M_{a_0} [MeV]	$982.5 \pm 1.6 \pm 1.1$	982.5 (Fixed)
$g_{a_0 K^+ K^-}$ [GeV]	$2.15 \pm 0.06 \pm 0.06$	$2.01 \pm 0.07 \pm 0.28$
$g_{a_0 \eta \pi^0}$ [GeV]	$2.82 \pm 0.03 \pm 0.04$	$2.46 \pm 0.08 \pm 0.11$
$g_{\phi a_0 \gamma}$ [GeV $^{-1}$]	$1.58 \pm 0.10 \pm 0.16^*$	$1.83 \pm 0.03 \pm 0.08$
$\text{BR}(\phi \rightarrow \rho\pi \rightarrow \eta\pi\gamma)$	$(0.92 \pm 0.40 \pm 0.15) \cdot 10^{-6}$	$(0.05 \pm 4 \pm 0.07) \cdot 10^{-6}$
$\text{BR}(\eta \rightarrow \gamma\gamma)/\text{BR}(\eta \rightarrow \pi^+\pi^-\pi^0)$	$1.70 \pm 0.04 \pm 0.03$	$1.70 \pm 0.03 \pm 0.01$
χ^2 probability	0.104	0.309

* Not a free parameter of the fit in this model. Calculated from other fit outputs.

reduces the probability of observation to $\sim 22\%$, but selects a class of event with a clear signature: four tracks and a low energy photon coming from the interaction point. In this analysis the whole KLOE dataset, $\sim 2.2 \text{ fb}^{-1}$, has been used. At the end of which we have observed 5 events in the data, while we were expecting 3.2 ± 0.7 background events from MC. A Cousin-Feldman approach has been used [5] and a 90% confidence level upper limit on the branching ratio has been obtained: $\text{BR}(\phi \rightarrow K^0 \bar{K}^0 \gamma) < 1.9 \times 10^{-8}$. This measurement excludes some of the theoretical predictions and is in agreement with expectations from other KLOE measurements (see figure 1 left, reference [4] and references therein).

2. $\gamma\gamma$ PHYSICS

KLOE has been making a pilot study for the search $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi^0\pi^0$ using 11 pb^{-1} from the 240 pb^{-1} taken at $\sqrt{s} = 1000 \text{ MeV}$ [6]. At this energy the background

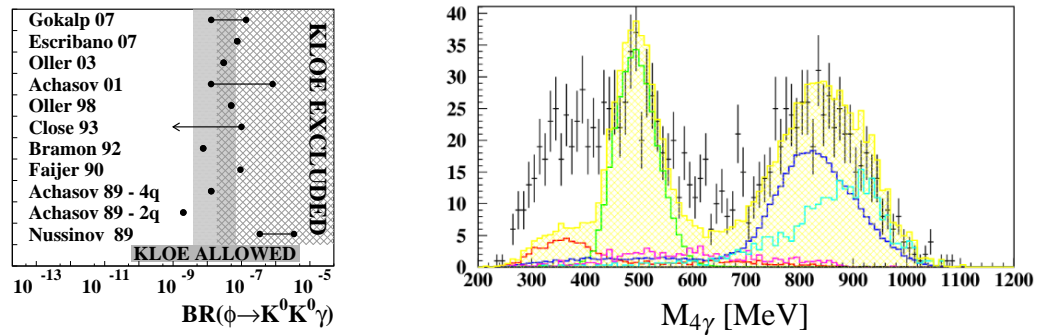


FIGURE 1. **Left:** comparison between theoretical predictions for the $\phi \rightarrow K^0 \bar{K}^0 \gamma$ branching ratio and KLOE upper limit. The grey area represents the expected range for the branching ratio using other KLOE results on scalar mesons. **Right:** search for $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi^0\pi^0$; fit to the invariant mass of the four photons, $M_{4\gamma}$, with MC shapes of expected source of background. Dots: data; attached yellow: total background; red: $\phi \rightarrow \eta\gamma \rightarrow \pi^0\pi^0\pi^0\gamma$; blue: $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$; green: $\phi \rightarrow K_S K_L$; cyan: $\phi \rightarrow f_0\gamma$; magenta: $e^+e^- \rightarrow \gamma\gamma$.

TABLE 2. Output of the fit imposing or not the gluonium content to be zero.

	Gluonium content forced to be zero	Gluonium content free
Z_G^2	fixed 0	0.115 ± 0.036
ϕ_P	$(41.4 \pm 0.5)^\circ$	$(40.4 \pm 0.6)^\circ$
Z_q	0.93 ± 0.02	0.94 ± 0.03
Z_s	0.82 ± 0.05	0.83 ± 0.05
ϕ_V	$(3.34 \pm 0.09)^\circ$	$(3.32 \pm 0.09)^\circ$
m_s/\bar{m}	1.24 ± 0.07	1.24 ± 0.07
χ^2 / dof	14.7/4	4.6/3
$P(\chi^2)$	0.005	0.20

from ϕ decays is very small. We have performed a fit to the four photons invariant mass ($M_{4\gamma}$), using the shapes of the known sources, see figure 1, right. The result of the fit is very poor $\chi^2/\text{dof} = 441/94$, showing an excess of events in the expected $\sigma(600)$ region, compared to what expected from MC, therefore pointing towards a search for the signal in the 240 pb^{-1} .

3. PSEUDOSCALAR PHYSICS

The ϕ meson decays about 1.3% of times into $\eta\gamma$, this implies DAΦNE is an η -factory. KLOE has collected one of the largest sample of η mesons in the world, about 10^8 .

$\eta - \eta'$ mixing and η' gluonium content [7]. The KLOE paper on $\eta - \eta'$ mixing [7], suggesting for a 3σ evidence of gluonium content in the η' meson, has triggered a large amount of discussion among theoreticians. Therefore we have decided to perform a new and more detailed study of this topic. We have considered η and η' in the quark mixing base as described in [8] ($|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_G|G\rangle$). The new fit we have performed has more constraints thus allowing an independent determination of more free parameters. We use the BR values from PDG 2008 [9] and the new KLOE results on the ω meson [10]. The fit has been performed both imposing the gluonium content to be zero or allowing it free. The results are shown in table 2: gluonium content of the η' is confirmed at 3σ level.

η decays into four charged particles [11]. KLOE has started to study the decays of the η into four charged particles, using 1.7 fb^{-1} of data. This decay is interesting because it allows us to probe the η internal structure exploiting the conversion of the virtual photon into a lepton pair [12]. It is also interesting because a non-CKM CP violating mechanism has been suggest to be present in this decay[13], and should manifest as an angular asymmetry A_ϕ , between the pion and the electron decay planes in the η rest frame. After background rejection a fit of the sidebands of the four tracks invariant distribution has been performed to obtain the background scale factors. Most of the background is due to ϕ decays, but there is still a non-negligible contribution from continuum events. Signal events have been counted in the η mass region, giving $BR(\eta \rightarrow$

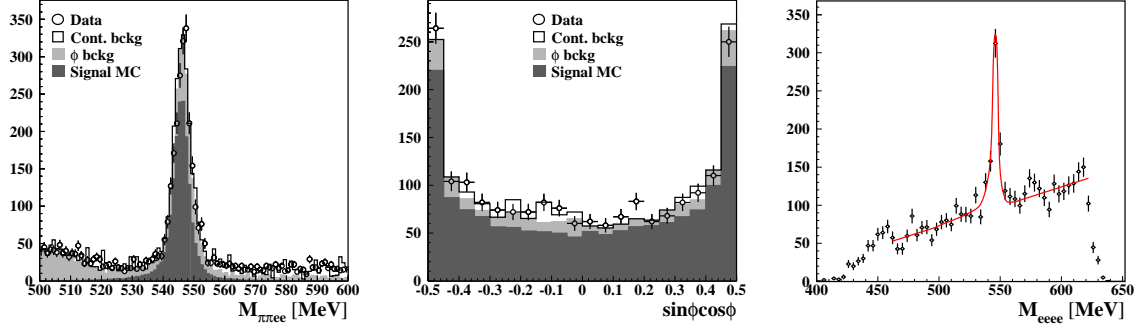


FIGURE 2. **Left and center:** $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ analysis; $\pi^+ \pi^- e^+ e^-$ invariant mass and angular asymmetry distributions. Dots: data. The black histogram is the expected distribution, i.e. signal MC (dark grey), ϕ background (light grey) and continuum background (white). **Right:** $\eta \rightarrow e^+ e^- e^+ e^-$ analysis; fit of the four electron invariant mass, M_{eeee} .

$\pi\pi ee) = (26.8 \pm 0.9_{Stat.} \pm 0.7_{Syst.}) \times 10^{-5}$ and $A_\phi = (-0.6 \pm 2.5_{Stat.} \pm 1.8_{Syst.}) \times 10^{-2}$ [11], see figure 2 left and center.

More recently KLOE has started studying the $\eta \rightarrow e^+ e^- e^+ e^-$ decay. This decay, together with the $\eta \rightarrow \mu^+ \mu^- e^+ e^-$, is interesting for the η meson form factor because there are only leptons in the final state. The analysis strategy is similar to the $\pi\pi ee$ one. Most of the background comes from continuum events and a small contribution is due to ϕ decays. The latter is subtracted from data using the MC shape. The number of events is obtained fitting the data distribution of the 4 electron invariant mass, M_{eeee} , with signal and background shapes (figure 2, right). From the fit we obtain 413 events. This constitutes the first observation of this decay.

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